Magnetic Sensing for VSW Mine Reconnaissance

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LONG-TERM GOALS

The US Navy is currently developing underwater technologies that will increase its war fighting capability in the littoral battle space. Requirements as documented in MNS-M042-85-93 (Mission Need Statement for Mine Countermeasures), MNS-M025-003-92 (Mission Need Statement for Shallow Water Mine Countermeasures), and OR 282-03-92 (Operation Requirements for Buried Mine Detector) indicate two capability gaps. These are the detection of buried mines and the reduction of acoustic clutter (false alarms), especially in the VSW areas. The shortcomings were initially addressed during the early 1990's at CSS, by demonstrating a towed, helium-cooled superconducting gradiometer under the Magnetic and Acoustic Detection of Mines (MADOM) ATD [1]. The long-term goal for this project is to provide a lower-cost, user-friendly magnetic sensor with comparable localization and classification capabilities for mine reconnaissance from autonomous underwater vehicles (AUVs).

OBJECTIVES

The Room Temperature Gradiometer (RTG) developed by Quantum Magnetics (QM), IBM Research, and the Coastal Systems Station (CSS) will be integrated into the Morpheus Autonomous Underwater Vehicle (AUV) developed by Florida Atlantic University (FAU). Capability of this integrated system will then be demonstrated for the detection, localization, and classification of buried, proud bottom, and moored mines in the VSW through land-based and at-sea testing.

APPROACH

The RTG, displayed in Figure 1, is a multi-element sensor utilizing fluxgate sensors and a novel feedback approach to attain high performance in mobile applications [2]-[4]. It measures five independent tensor-gradient components, which completely characterize the local magnetic-gradient field [2]-[4]. This multi-channel approach offers the same accurate 3-dimensional localization, moment-vector classification, and a multiple-target capability demonstrated in MADOM that has not been achieved using total-field magnetometers.

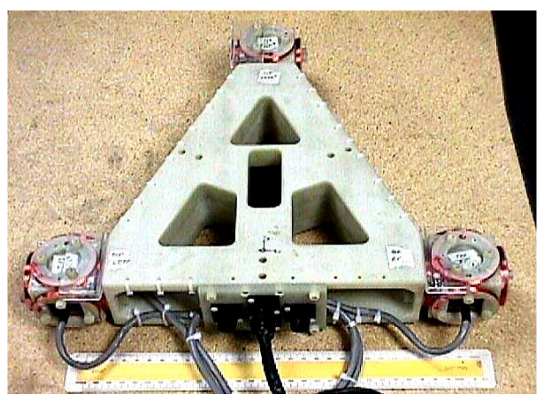


Figure 1. Photograph of the RTG sense head featuring three primary sensing fluxgate triads at the three corners of the triangle and a reference fluxgate triad in the center of the triangular frame.

The ideal environment for sensitive magnetic sensors operating onboard moving platforms is one that is ferromagnetically clean, free of metallic eddy current sources, and distant from electrical and electronic equipment, power plants, electrical distribution paths, and propulsion units. For example, the superconducting gradiometer successfully demonstrated in the MADOM ATD was operated in a magnetically clean trailing tow body well removed from significant platform-noise sources. The ability to integrate high performance magnetic sensors onboard small AUVs producing significant magnetic noise is an emerging technology area [5], [6].

The Morpheus AUV is a new sensor platform developed for VSW mine reconnaissance [7]. Although the vehicle was not originally designed to have a low magnetic signature, it is a good candidate for magnetic-sensor operation compared to other AUVs currently available. The primary construction materials have relatively low magnetic signature. In particular, the vehicle's superstructure is injection-molded plastic. The vehicle is built up from modular sections that can be flexibly configured to optimize system performance. Hence a configuration can be implemented in which the RTG is mounted in the nose, removed as far as possible from the propulsion unit and fin actuators, and the remaining significant noise sources can be distributed in the body to minimize their magnetic noise contribution to the sensor. The vehicle's narrow torpedo-like shape when elongated to maximum length, nominally nine feet, simplifies platform-noise compensation. In particular, such a source distribution, in contrast to a distributed 3D source, will appear more as a single dipole, with signature easily monitored using auxiliary magnetic sensors for compensation. Simple retrofit of some existing vehicle magnetic components, such as the drop weight, mechanical connectors, and small batteries, with non-magnetic materials can be instituted to reduce the signature.

This CSS effort is closely coordinated with the ONR-sponsored SBIR "Integration of Advanced Magnetic Sensors into Underwater Vehicles to Provide High-Quality Spatiotemporal Magnetic Data" to QM in conjunction with FAU. These two coordinated efforts involve three-way teaming between the CSS, QM, and FAU. The plan for the two coordinated projects is described below. The RTG currently configured for land-based operation will be re-configured for operation onboard the Morpheus AUV, specifically resized to fit into the target vehicle. Requirements for platform-noise mitigation will be identified, and signature-reduction and signal-processing compensation techniques will be developed as required to attain successful RTG performance in the Morpheus AUV. Based on these developments, the RTG will be integrated into the Morpheus AUV. Then land-based and at-sea operability tests will be conducted, and the system will finally be demonstrated against a target minefield. The CSS will take the lead in direction and coordination of this project, the implementation of localization algorithms, and the development of platform-noise mitigation techniques. QM will re-design and manufacture the RTG for AUV demonstration, will be responsible for sensor integration, and will participate in the development of platform-mitigation techniques. FAU will provide and support the Morpheus AUV, will participate in the sensor/AUV interface design, and will be responsible for test direction of the final underwater demonstration. To assure successful demonstration, all three facilities will be major participants in the field-testing and the demonstration.

In addition to this effort for system integration and demonstration, the CSS will support the VSW MCM Analysis of Alternatives Study Group. In particular, we will provide technical information on magnetic-sensor requirements and capabilities, measure the magnetic signatures of a substantial number of VSW naval mines and provide a database of probability-of-detection/classification (PdPc) curves for this set of mines.

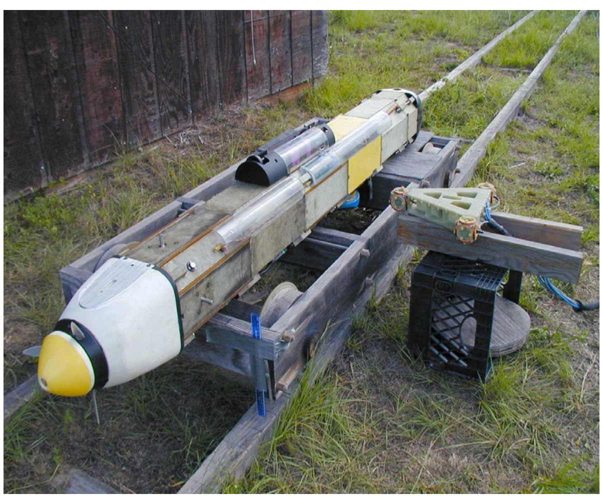
WORK COMPLETED

This project is a new start for FY 2000 with the following work being accomplished.

- Established teaming relationships and coordinated multi-laboratory approach.
- Readied two in-house RTG sensors to support platform noise experiment.
- Developed unique data-acquisition and magnetic analysis software for vehicle characterization.
- Conducted one week of magnetic measurements on AUV Morpheus at the CSS nonmagnetic facility.
- Recorded (in cooperation with QM and FAU) extensive signature data of the Morpheus AUV both unpowered and powered and while static and in motion (simulated underwater motion was produced through the use of the 3-axis CSS nonmagnetic motion table).

RESULTS

Models and affiliated analysis software have been developed to measure the magnetic signature of a vehicle with a complex source distribution (in contrast to a single dipole source) and to evaluate the performance of the RTG onboard candidate AUVs. An extensive data set has been collected using RTGs to measure magnetic properties of the Morpheus AUV. Experiments have been conducted to measure the magnetic signature of the AUV by passing the vehicle by a stationary RTG. In addition, magnetic measurements were conducted with the AUV operated unpowered and powered both stationary and in motion. An extensive data set has been collected with two RTGs mounted in various positions relative to the Morpheus AUV. Based on our experience, this represents the best data available to develop approaches to integrate high performance magnetic sensors onboard this class of AUVs. Preliminary assessment of the data is encouraging.



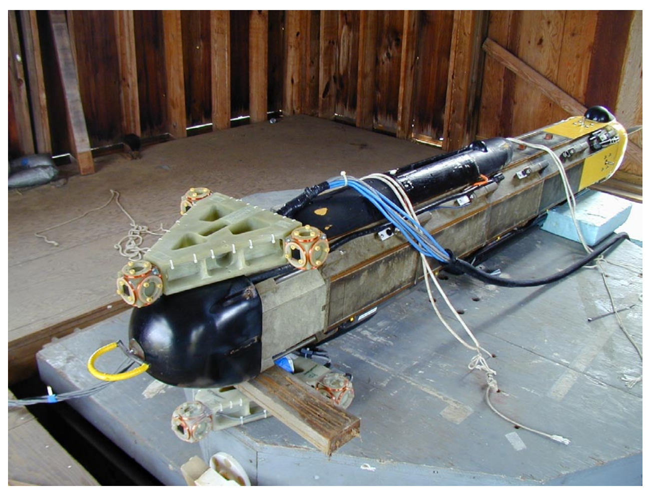


Figure 2. Experimental arrangements to measure magnetic properties of the Morpheus AUV: (a) configuration displayed on the left hand side is used to measure the magnetic signature by moving the vehicle past a stationary RTG and (b) configuration on the right hand side is used to measure (note dual RTG sensors) magnetic characteristics of the vehicle operated unpowered and powered both stationary and in motion with the vehicle mounted on a platform-motion simulator.

- The magnetic signature of the vehicle unpowered is relatively small, with the most significant contributions associated with fin actuators and the propulsor. One consequence of this result secondary to this effort is that the AUV can be operated in a minefield with low risk of triggering a mine.
- Noise to the sensor from the vehicle unpowered in motion is not significantly greater than intrinsic noise stationary.
- A RTG can be operated onboard the AUV while in motion with the electrical subsystems powered. The fin actuators and the propulsor represent the major noise sources. The noise levels are significantly reduced if the sensor is operated rigidly mounted in the nose of the vehicle away from these major noise sources.

Analysis of this data set will be completed early in FY 2001. These results will be used for efforts in FY 2001 to develop a mockup of the Morpheus AUV, to identify specific signature-reduction approaches, and to develop platform-noise compensation concepts and signal processing.

IMPACT/APPLICATIONS

The U.S. Navy has pioneered the 5-channel tensor-gradiometer approach to provide localization and classification capabilities unachievable using current Fleet magnetometers such as the ASQ-81/208. Magnetic sensing can greatly enhance mine reconnaissance and hunting operations. Magnetic sensing is effective against totally buried ferrous targets since the magnetic signals generated by the target are neither attenuated nor distorted passing through the sea floor. In the MADOM sea testing, more than 98% of the acoustically mine-like clutter was not magnetically mine-like. The sensing envelop for a magnetic tensor gradiometer is omni-directional so that a single sensor without hardware or software reconfiguration is effective not only against bottom mines, but also against mines tethered throughout the water column, including near-surface moored mines. Magnetic sensing can also add operational robustness in difficult acoustic environments that arise from interfering reverberations, bottom topographical features, rock formations, kelp beds, coral reefs, schools of fish, and other biologics. In FY 1999, the gradiometer utilized in MADOM was the premiere sensor in an unscripted survey to locate unexploded ordnance in the Technology Demonstration of the Mobile Underwater Debris Survey System (MUDSS), a system prototype utilizing ONR-sponsored advanced mine reconnaissance sensors for this dual-use task [8]. It successfully detected buried targets and was effective in a bay environment that limited the performance of the acoustic and optic sensors utilized in the test.

The RTG integrated into the Morpheus AUV will provide a powerful detection/classification tool for VSW MCM mission without the need of diver support and the accompanying risk to human life. This system will be small, low-cost, reliable and easily maintained. Synergistic fusion with acoustics will give a high probability of detection and classification and will significantly reduce the overall false alarm rate. It will provide buried mine detection and will enhance VSW operations under conditions that may limit acoustic performance. This system can also be applied to geophysical characterization to map underwater magnetic fields and gradients.

The experience gained from this integration project, specifically the platform-noise compensation algorithms developed under this effort, can be subsequently applied to a wide range of magnetic sensors and platforms. The results of this demonstration will be utilized in concept development of new reconnaissance paradigms with swarms of magnetic sensors on multiple platforms operating synergistically to increase the effectiveness of operations. In addition, the platform-noise mitigation algorithms will be applied to operate more sensitive magnetic sensors, such as a high critical temperature superconducting gradiometer (HTSG), successfully onboard AUVs and other underwater, surface, and airborne platforms.

TRANSITIONS

The addition of capable, small, low-cost magnetic sensors onboard remotely operated, or autonomous sensing platforms will enhance the Navy's ability to do mine reconnaissance and related missions quickly and safely and will support performance, size, and cost requirements currently in place for the VSW MCM mission.

Its capabilities can be applied to SOF and EOD diver applications, including the detection of unexploded ordnance. In the FY 1999 Technology Demonstration of the Mobile Underwater Debris Survey System (MUDSS), the diver reacquisition/target identification process following an initial detection/classification survey proved to be problematic using the USN MK 25, a EOD diver-portable cesium-vapor total-field magnetometer having only audio discrimination for target detection/ classification [8]. The RTG can provide automated visual display of target 3D position and 3-component magnetic moment not possible using the MK 25. Similar application to man-portable land-based operations is obvious.

RELATED PROJECTS

As mentioned earlier in this paper, this project is integrated with a SBIR "Integration of Advanced Magnetic Sensors into Underwater Vehicles to Provide High-Quality Spatiotemporal Magnetic Data" to QM in conjunction with FAU sponsored by ONR Code 322OM. Independent work in AUV development at FAU being leveraged by this project is also supported by ONR Code 322OM and 322OE. ONR Code 322GG has supported the development of localization algorithms for magnetic detection of mines, including a FY 1999-2000 effort dedicated to tracking algorithms that will be utilized for target localization with the RTG. The RTG was initially funded by the Special Operations Command (SOCOM). A land-based version of the RTG for UXO applications has been developed and was delivered to the CSS in FY 2000 under a Phase II SBIR to Quantum Magnetics funded by the Office of Secretary of Defense (OSD).

ONR Code 322GG has more recently supported the development of a high Tc superconducting gradiometer (HTSG) cooled by liquid nitrogen to pursue longer range detection with significantly reduced logistics and support requirements compared to its helium-cooled predecessor used in MADOM [9]. The RTG and HTSG developments are very synergistic. They use a similar sensor design approach and essentially identical signal processing. Moreover they provide a range of solutions for high quality target localization and classification to support varying mission and operational requirements such as detection range, sensor cost, and platform compatibility.

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